Optical and Thermal Requirements for Agricultural and Environmental Monitoring

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Introduction

- Remote sensing methods allow for rapid assessment of the environment and agriculture over wide areas.
- Remote sensing methods are most effective when optimized:
  - Spectrally
  - Spatially
  - Temporally
  - Radiometrically
- Thus, we aim to define the requirements.

What are the applications?

- Land use/ land cover change
- Vegetation health/ global crop forecasting
- In-field crop stress mapping/ precision farming
- Dry (flammable) biomass cover
- Verification of:
- Crop insurance claims
- Conservation practices:
- Cover crops
- Tillage

So what do we specifically want to measure?

- Plant cover/ leaf area index
- Vegetation stresses:
- Plant nitrogen (chlorophyll content)
- Plant water
- Dry cellulose (crop residues/ plant litter/ non-photosynthetic vegetation)
- Evapotranspiration
- Atmospheric vapor for correction to surface reflectance.

Spectral bands: visible through SWIR

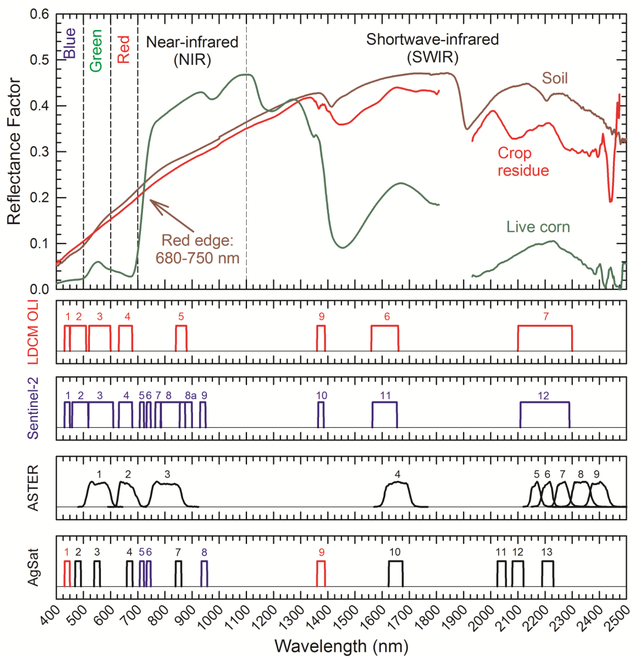


Figure 1. Spectra of soil, crop residue and green vegetation, proposed bandwidths for the Landsat Data Continuity Mission (LDCM)'s Operational Land Imager (OLI, Sentinel-2, and an ideal agricultural satellite mission (AgSat), and the spectral response functions for the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor.

Spectral bands: TIR

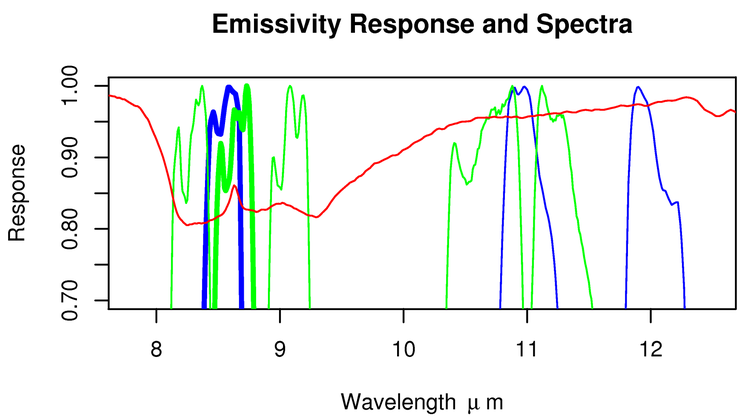


Figure 2. TIR emissivity response and spectra. Blue: MODIS bands 29, 31, 32. Green: ASTER bands 10 – 14. Red: Sandy soil emissivity, SGP97 experiment, El Reno, OK.

Disclaimer: This concept is based on discussions about satellite data requirements for agricultural monitoring and does not represent official USDA or ARS policy.

Remote sensing live vegetation cover and health

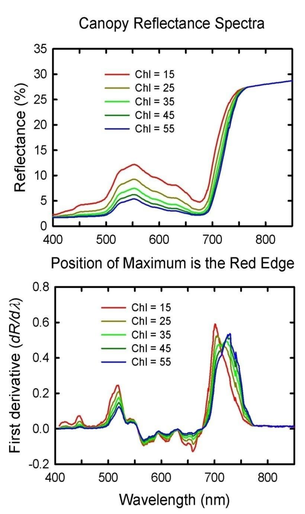


Figure 3. Chlorophyll content and the Red Edge.

- Most plant cover/ condition remote sensing use Normalized Difference Vegetation Index (NDVI):

$$NDVI = \frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d}$$

- NDVI not overly sensitive to chlorophyll.
- The position of the Red Edge can indicate nitrogen stress conditions.
- Red edge indices are sensitive to chlorophyll (bands shown are for Sentinel-2):

$$\mathrm{Re}\,d\ EdgeNDVI = \frac{R_{740} - R_{705}}{R_{740} + R_{705}}$$

$$MTCI = \frac{R_{740} - R_{705}}{R_{705} + R_{665}}$$

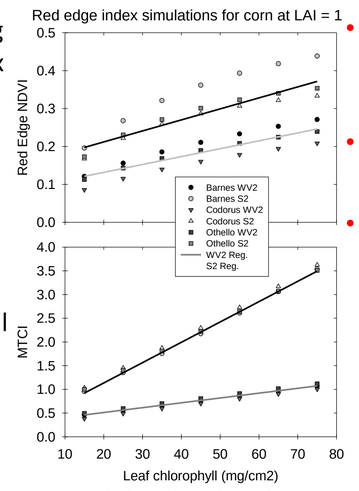


Figure 4. Red Edge Index simulations for Worldview-1 and Sentinel-2 for corn at LAI = 1.

- Red Edge indices require at least one band at 720 nm (Worldview-2, RapidEye), plus red, NIR bands.
- The MERIS Terrestrial Chlorophyll Index (MTCI) least affected by soil.
- Red Edge is better imaged with bands at 705 and 740 nm:
  - Sentinel-2 mean soil MTCI = 0.82, std. dev. = 0.29, N = 4257
  - Worldview-2 (one band at 720 nm) mean soil MTCI = 0.91, std. dev. = 3.29

Remote Sensing of Canopy Water and Evapotranspiration

- Soil moisture deficiencies cause leaf stomata to close up:
  - Evapotranspiration and photosynthesis decrease;
  - Vegetation heats up;
  - Yields can be negatively impacted.
- NIR and SWIR band at 1610 – 1650 nm can be used to estimate canopy water content:
  - SWIR band reflectance inversely related to leaf water content.
- LDCM's split thermal infrared (TIR) bands (10.8 and 12.0 μm) will allow for estimation of canopy evapotranspiration (ET).
- Additional thermal bands at 8.6 and 9.1 μm will help improve emissivity estimation.

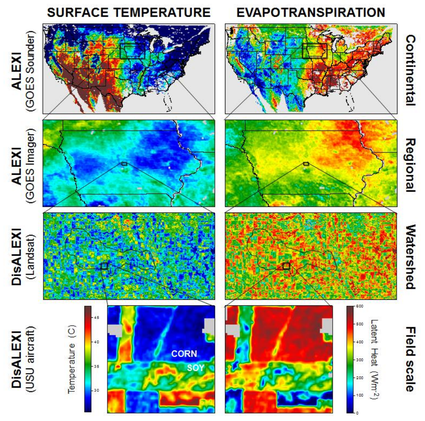
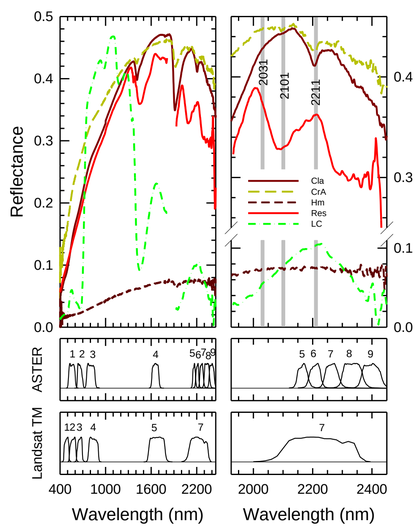


Figure 5. Remote sensing of evapotranspiration at different scales.

Remote sensing dry biomass

- Dry biomass (senescent vegetation) serves a number of purposes:
  - As crop residues left on a surface for conservation tillage practices
  - As a feedstock for cellulosic biofuels
  - As an indicator of rangeland health and grazing
  - As fuel for wildfires.



- Below 2000 nm, dry biomass and soils can be spectrally similar.
- Broad Landsat TM bands cannot discriminate narrow spectral features of dry vegetation components.
- Cellulose Absorption Index (CAI) ideal for sensing dry vegetation:

$$CAI = 100\left[\left(R_{2030} + R_{2210}\right)/2 - R_{2100}\right]$$

- CAI targets an absorption occurring at 2100 nm present for all sugars, including cellulose.
  - Most soil minerals do not have absorptions in this region.
- CAI has a linear relationship between bare soil, 100% dry biomass cover.

Figure 6A. Intensively tilled field

B. Conservation tilled (no-tilled) field

C. Prescribed rangeland burn, image courtesy Wyoming Wildlife and Natural Resource Trust

D. Simi Valley, CA, Oct. 14, 2008. (Associated Press)

What would an ideal agricultural satellite look like?

Band number	Band center and bandpass (nm)	Region	Parameter	Indices	Heritage
1	443 (433–453)	Blue	Coastal/Aerosols		LDCM
2	480 (470–490)	Blue	Aerosols	EVI	Landsat TM
3	550 (540–560)	Green	Chlorophyll	GNDVI, Red Edge indices	Landsat TM
4	670 (660–680)	Red	Vegetation cover	EVI, NDVI	Landsat TM
5	705 (695.5–712.5)	Red edge	Chlorophyll	Red Edge indices	Sentinel-2
6	740 (732.5–747.5)	Red edge	Chlorophyll	Red Edge indices	Sentinel-2
7	850 (840–860)	NIR	Vegetation cover	EVI, NDVI, NDWI	Landsat TM
8	940 (950–960)	NIR	Water vapor		Sentinel-2
9	1375 (1360–1390)	SWIR	Cirrus clouds		LDCM
10	1650 (1625–1675)	SWIR	Vegetation water content	NDWI	Landsat TM
11	2040 (2025–2055)	SWIR	Cellulose	CAI	New band
12	2100 (2080–2120)	SWIR	Cellulose	CAI	New band
13	2210 (2190–2230)	SWIR	Cellulose	CAI	New band
14	8.6 (8.475–8.825) μm	TIR	Emissivity		ASTER
15	9.1 (8.925 - 9.275) μm	TIR	Emissivity		ASTER
16	10.8 (10.3–11.3) μm	TIR	ET, Vegetation stress	DisALEXI	LDCM
17	12.0 (11.5–12.5) μm	TIR	ET, Vegetation stress	DisALEXI	LDCM

- Temporal resolution requirements: < 7 days, 5 day or better ideal.
- Pixel size: 60 m maximal in visible through SWIR (VSWIR), 100 m TIR;
  - 20 m ideal VSWIR, 60 m TIR.
- Nadir looking.
  - Swath width constrained to a maximum 20° off-nadir view angle:
    - Minimizes BRDF problems;
    - Minimizes obscurement of soil by canopy, residue;
    - Ensures radiometric accuracy in TIR.
- Quantization = 12 bits.
- Signal-to-Noise Ratio (SNR) requirements: >250.
- Narrower ASTER-type bands in SWIR to discriminate cellulose absorption.

References:

- Anderson, M.C., et al. 2011. Mapping daily evapotranspiration at field to continental scales using geostationary and polar orbiting satellite imagery. Hydrol. Earth Syst. Sci. 15:223–239.
- Brown, D.J., K.D. Shepherd, M.G. Walsh, M.D. Mays, and T.G. Reinsch. 2006. Global soil characterization with VNIR diffuse reflectance spectroscopy. Geoderma 132:273-290.
- Dash, J. and P.J. Curran. 2007. Evaluation of the MERIS terrestrial chlorophyll index (MTCI). Advances in Space Research 39:100-104.
- Gitelson, A.A. and M.N. Merzlyak. 1996. Signature analysis of leaf reflectance spectra: algorithm development for remote sensing of chlorophyll. J. Plant Physiol. 148:495-500.
- Serbin, G., E.R. Hunt, Jr., C.S.T. Daughtry, G.W. McCarty, and P.C. Doraiswamy. 2009a. An Improved ASTER Index for Remote Sensing of Crop Residue. Remote Sensing 1:971-991.
- Serbin, G., C.S.T. Daughtry, E.R. Hunt, Jr., D.J. Brown, and G.W. McCarty. 2009b. Effect of soil spectral properties on remote sensing of crop residue cover. Soil Science Society of America Journal 73:1545-1558.
- Serbin, G., E.R. Hunt, Jr., C.S.T. Daughtry, D.J. Brown, G.W. McCarty, and P.C. Doraiswamy. 2010. Assessment of Spectral Indices for Crop Residue Cover Estimation Proc. Proceedings of the 2010 IEEE International Geoscience and Remote Sensing Symposium, Honolulu, HI. July 25, 2010. IEEE.